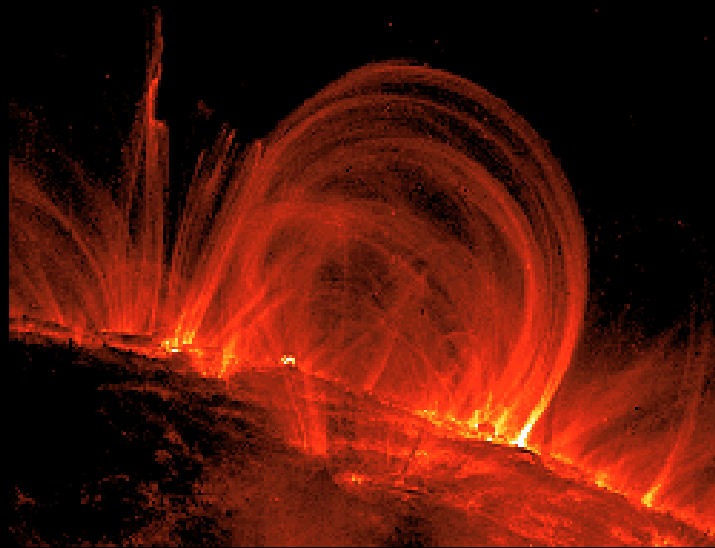


Magnetic Reconnection



Paul Cassak
Advisor – Jim Drake
University of Maryland – College Park
2003 HPC Summer School



Solar Flares



<http://science.msfc.nasa.gov/ssl/pad/solar/flares.htm>

Magnetohydrodynamics

$$\rho \frac{d\vec{v}}{dt} = -\vec{\nabla} p + \vec{J} \times \vec{B} = -\vec{\nabla} p + \frac{B^2}{2\mu_0} \vec{\nabla} + \frac{1}{\mu_0} (\vec{B} \cdot \vec{\nabla}) \vec{B}$$

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$$

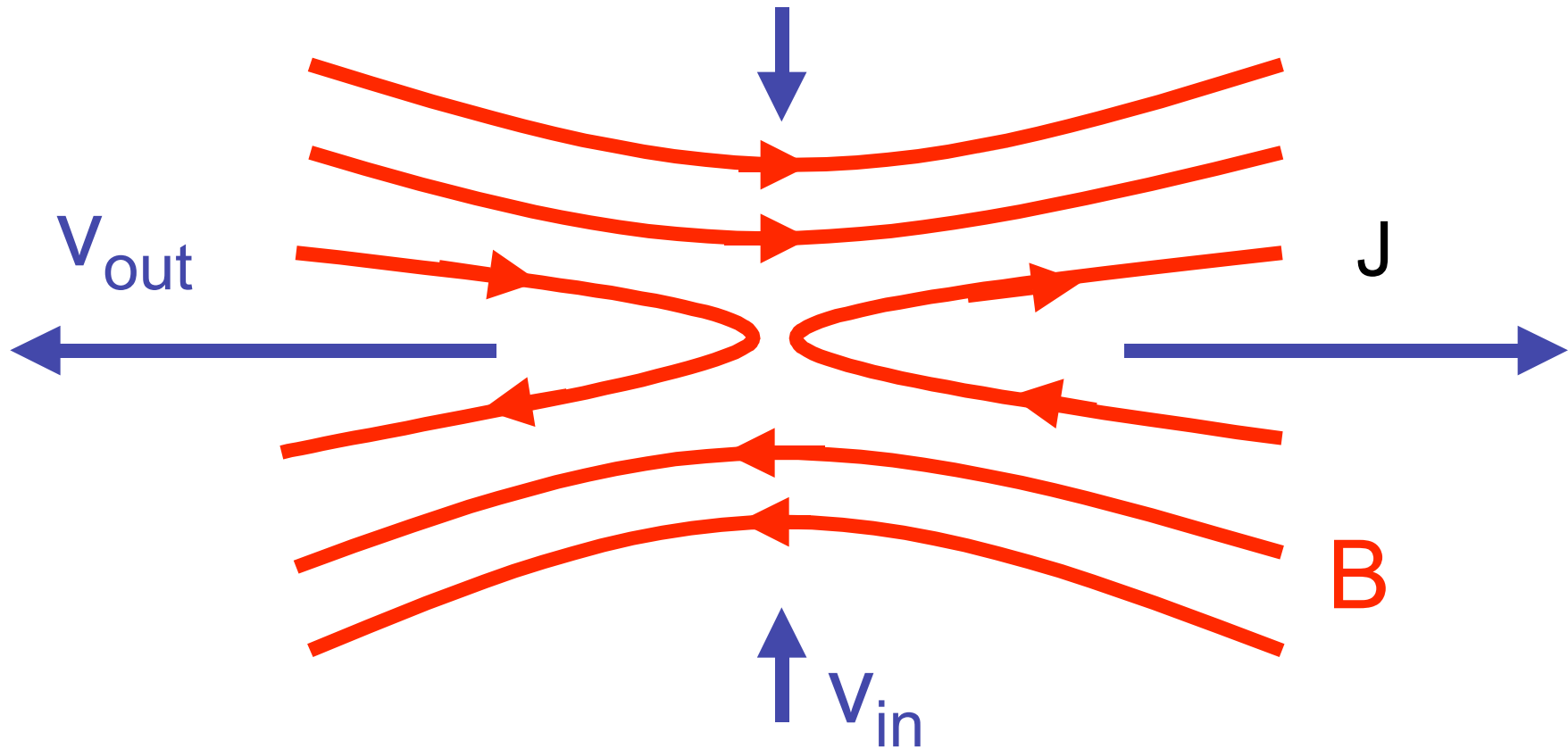
Magnetic
Pressure

Magnetic
Tension
(Curvature)

“Alfvén waves” travel at speed

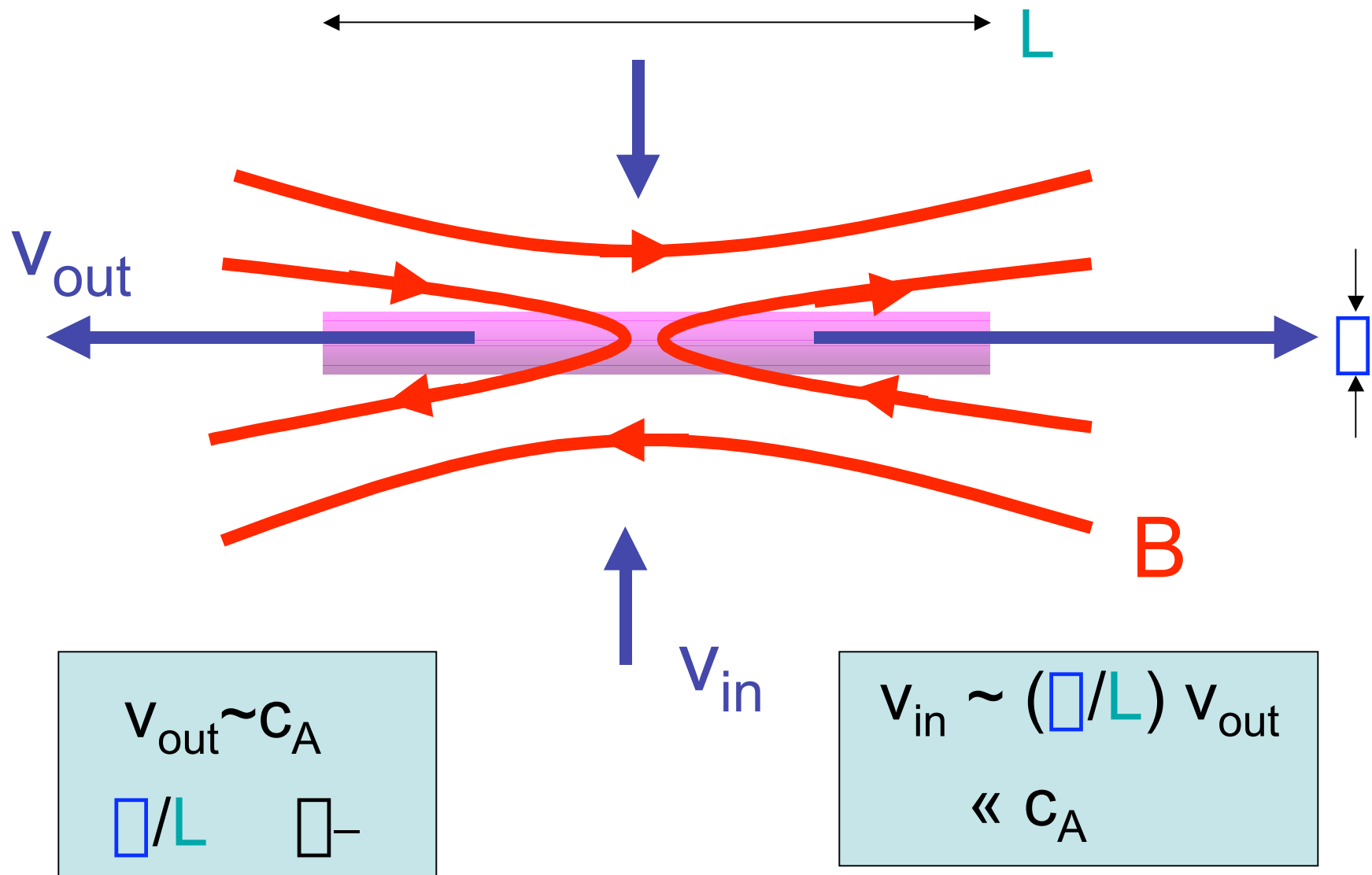
$$c_A = \sqrt{\frac{B^2}{\mu_0 \rho}}$$

General Mechanism

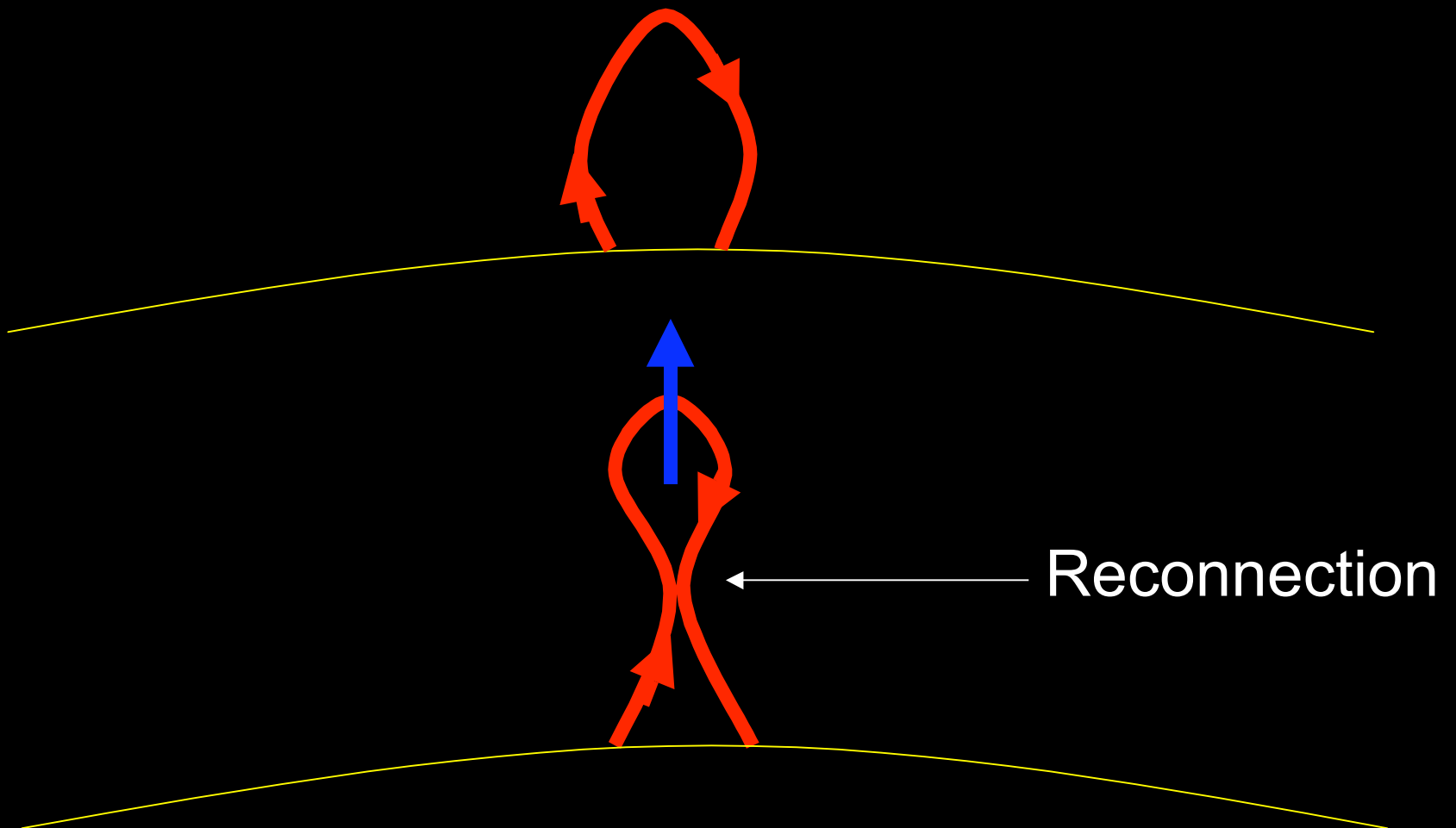


Strong observational and experimental support

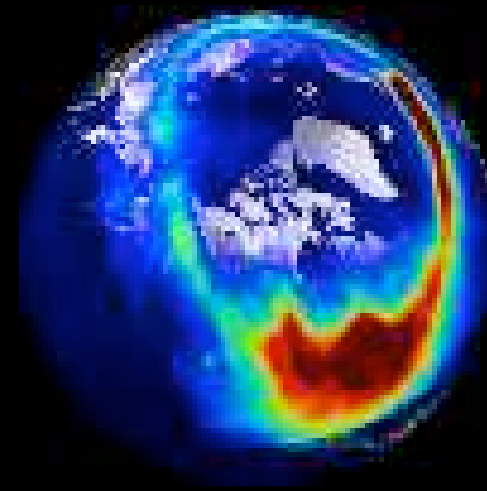
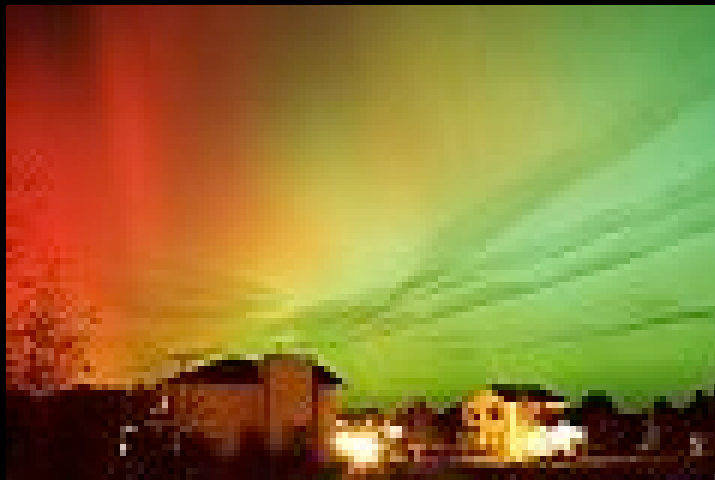
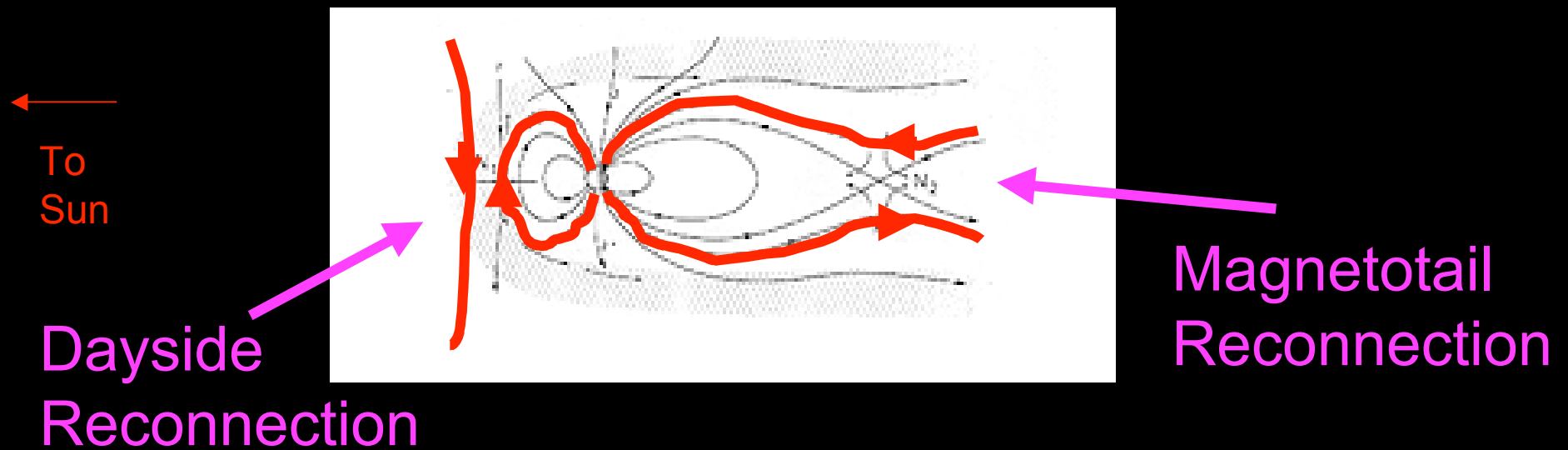
Sweet-Parker Model



Solar Flare Mechanism



Another Application - Magnetospheric Physics



A Problem with Sweet-Parker

Scaling analysis $\square \quad v_{\text{in}} \quad (\square)^{1/2} v_{\text{out}}$

For a solar flare,

Time (SP Theory) $\sim 10^7 \text{ sec}$

Time (Observed) $\sim 10^3 \text{ sec}$

For a substorm,

Time (SP Theory) \sim

Time (Observed) $\sim 30 \text{ min}$

Fix #1 – “Collisionless reconnection”

Kinetic Theory \square Generalized Ohm's Law

Hall Effect \square Whistler waves \square Fast Reconnection

Fix #2 – “Anomalous resistivity”

Sweet-Parker would agree with observation

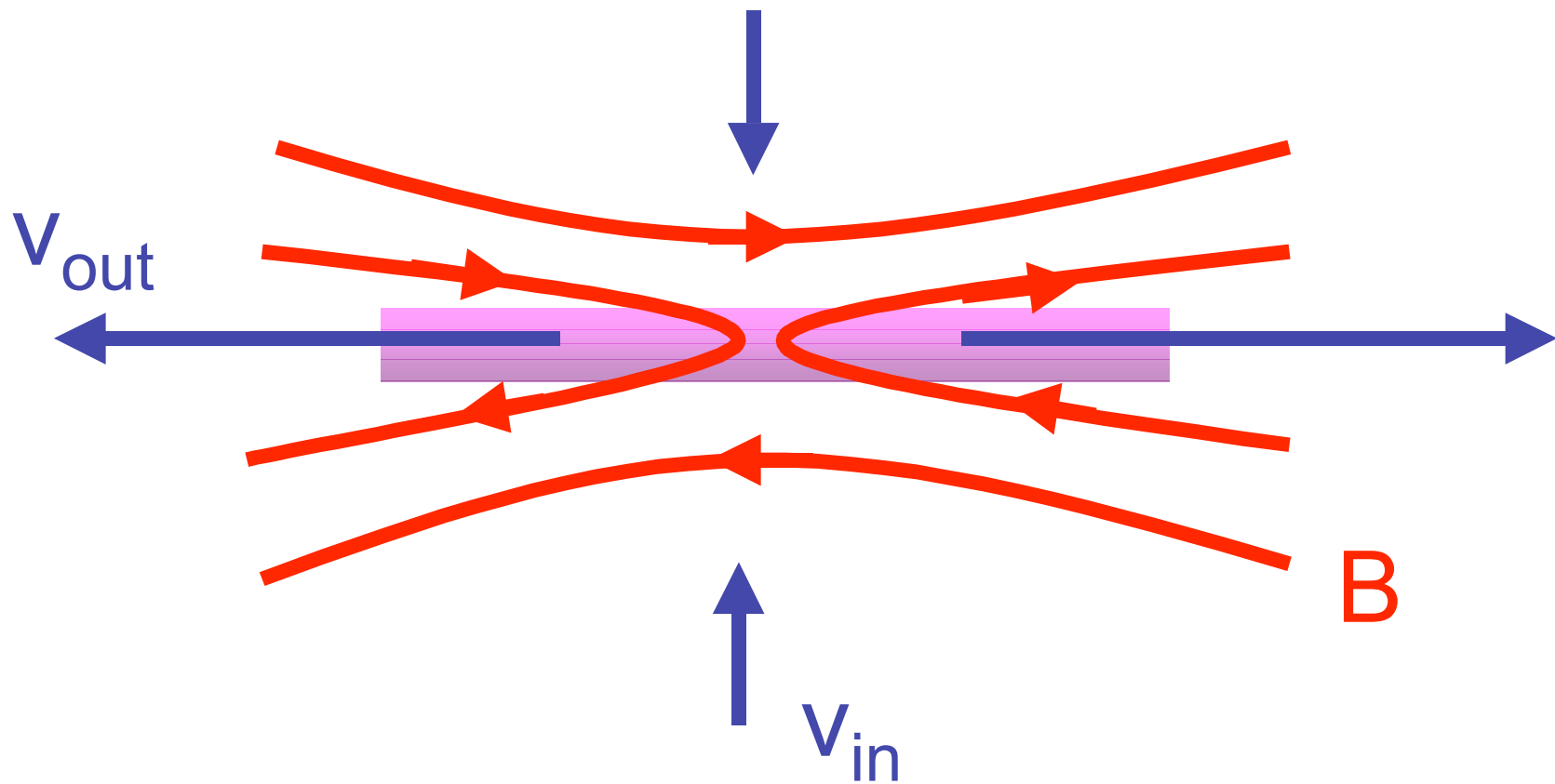
if $\eta_{\text{anomalous}} \gg \eta_{\text{classical}}$.

But, what causes it and how?

Turbulence?

Problem #2 with Sweet-Parker

Sweet-Parker is manifestly a 2_D theory – what happens in 3D?



Current Research

The Code:

- Multiple capabilities
 - MHD / 2 fluid
 - 1 fluid + 1 particle (hybrid)
 - full particle
 - switches for kinetic effects
 - 2 _ or 3 dimensions
- Periodic boundary conditions
- Fully Relativistic
- Explicit time-stepping
 - trapezoidal leapfrog
- Massively parallel

The Computer



- Lawrence Berkeley National Laboratory
- NERSC IBM SP RS/6000 (*Seaborg*)
- 380 compute nodes (6,080 processors)
- Peak performance 1.5 GFlops/sec
- Total Disk Storage 44 Terabytes

2D Simulations

2 1/2 D

Hall MHD

Strong Guide Field

($B_g = 5B_0$)

Coherent Initial

Perturbation

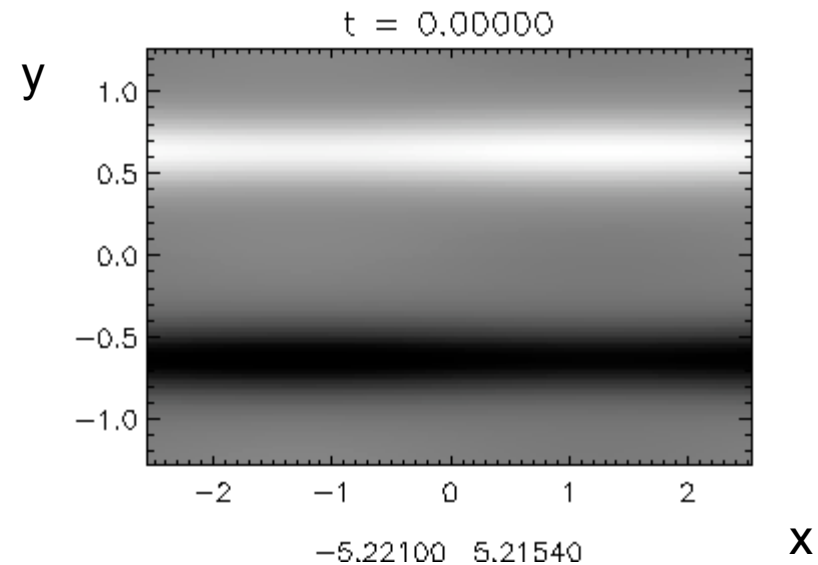
256 x 128

$w_0 = 0.2$

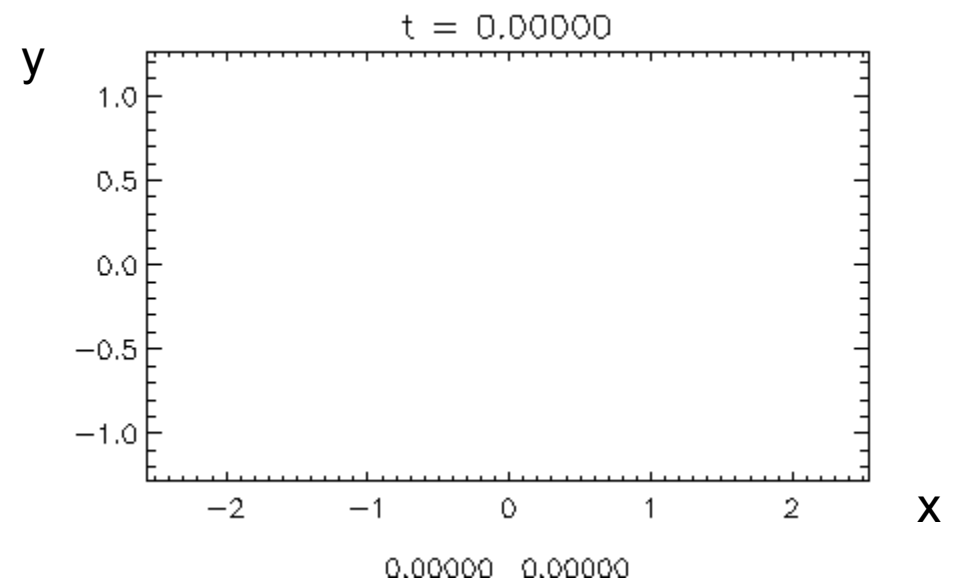
$dt = 0.0025$

$dx = dy = 0.02$

z component of the current, J_z



x component of the ion current, J_{iz}



3D Simulations

3D

Hall MHD

Strong Guide Field

($B_g = 5B_0$)

“Random” Initial

Perturbation

256 x 128 x 64

$w_0 = 0.2$

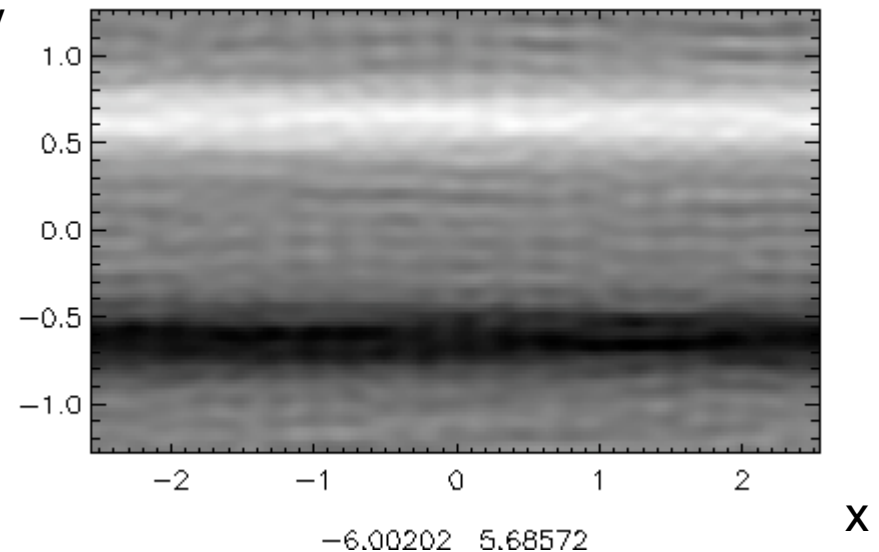
$dt = 0.0025$

$dx = dy = 0.02$

$dz = 0.4$

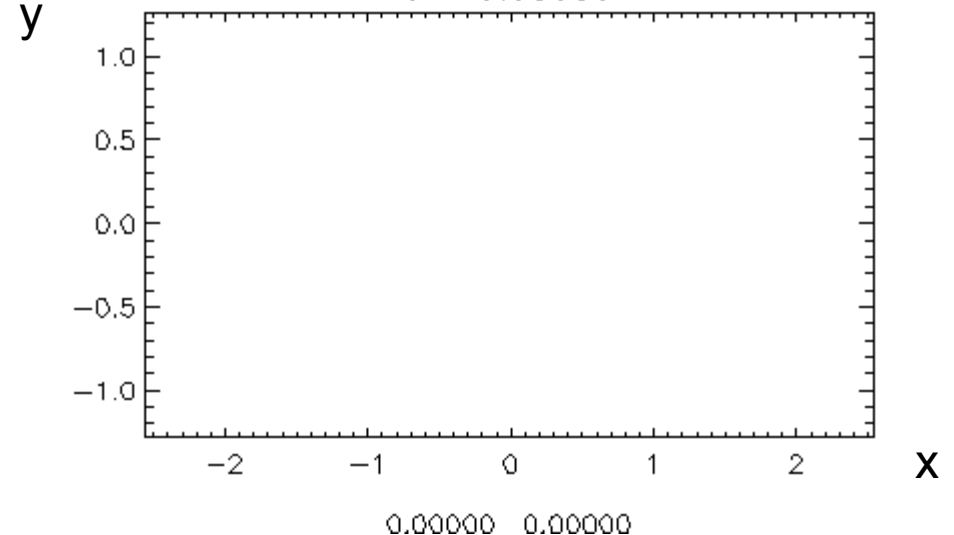
z component of the current, J_z

$t = 0.00000$



x component of the ion current, J_{iz}

$t = 0.00000$



Conclusions

- Reconnection is an important and ubiquitous physical phenomenon that allows for the **explosive** conversion of magnetic energy to kinetic energy.
- Much understanding has been obtained, but much work remains, including theoretical, experimental, astronomical observation and **computational**.

Dedicated to:



Marco Antonio Cândido Ribeiro